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Studies of Soil Moisture and Spacing for Seed Crops of Carrots and Onions

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INTRODUCTION

Opinions among growers differ on how frequently seed crops should be irrigated. High, moderate, and low soil moisture are all advocated. Crops grown under irrigation respond differently under varying conditions of soil type, climate, and such cultural details as spacing. The amount and frequency of irrigation necessary for the most profitable yield depend upon the combination of these and perhaps other factors.

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The number of plants per foot, row, or unit-area of soil, planned or resulting from poor stand, is also known to affect the yield of many crops. With seed carrots, a 3- by 3-foot spacing is common in some sections, while closer spacing within 3-foot rows is used more often in others. Different systems of spacing have likewise been practiced with seed onions.

Few, if any, reports have been published on spacing experiments with carrot- and onion-seed crops. Some studies (*9, 10*)[2] on the effect of soil moisture have recently appeared, but they were conducted at one spacing. It appeared probable that with a spacing closer than normal, yields higher than usual might be obtained, provided the plants received an adequate supply of water and nutrients. At the time these seed-production studies were planned, reports by Krantz (*8*), Kelley, Hunter, and Hobbs (*7*), and other workers indicated that results of considerable value could be obtained by studying simultaneously such factors as spacing, soil moisture, and fertility in one experiment. The experimental field designs necessary for studying several factors at once are much more efficient than those required for one factor alone and give answers to several questions, depending upon how many factors are combined in the study. Most of the results reported herein are based on experiments in which soil moisture and spacing have been studied in combination.

EARLIER INVESTIGATIONS

MacGillivray (*9*) and MacGillivray and Clemente (*10*) conducted irrigation experiments in California with seed crops of onions and carrots, respectively. Their work was started before the studies in Utah, discussed in this publication, were begun. By chance, the varieties used in both the California and Utah investigations were identical. Also the number of irrigations applied in the various treatments were often the same, or nearly so. In the California studies, however, each crop was spaced uniformly, and the effect of spacing was not taken into consideration. Soil-moisture records were based on oven-dried soil samples.

With Yellow Sweet Spanish onions, MacGillivray concluded that high soil moisture, or a minimum of 10 inches of water by irrigation in addition to winter rainfall, is desirable for high yields at Davis, Calif. He also found that the germination and size of the seed produced were not materially affected by irrigation. The soil data indicated that during the 3 months preceding seed harvest the available soil moisture was removed from the top 4 feet of soil.

In the study with carrot-seed crops by McGillivray and Clemente it was again concluded that high soil moisture favored high seed yields. The viability and size of the harvested seed were not noticeably affected by the treatments. Seed carrots were found to remove soil moisture to a depth of 5 to 6 feet.

In making soil-moisture studies it is important to know how the soil moisture is determined. Work by Richards and Weaver (*13*)

[2] Italic numbers in parentheses refer to Literature Cited, p. 26.

and Kelley, Hunter, and Hobbs (*7*) has shown that there is little relation between soil-moisture tension and a given percentage of available water in soil of various textures. The tension more often indicates how much moisture a plant can remove from the soil. Taylor (*14*) has recently explained in simple terms the relationship between plant growth and soil-moisture tension.

The depth at which samples should be taken is also a problem. It has been generally known for some time from the work of Weaver and Bruner (*15*) that the carrot has a strong, deep, extensively developed root system and that the onion, in contrast, has a shallow, fibrous system with a minimum of branching. As pointed out by MacGillivray and Doneen (*11*), however, in their soil-moisture studies, neither carrots nor onions exhibit typical symptoms of wilting. Therefore, more detailed knowledge of their soil-moisture requirements is desirable. Bouyoucos and Mick (*1*) in 1940 described how measurement of soil moisture could be obtained as often as desired by the electrical resistance in calibrated gypsum (plaster-of-paris) blocks buried at suitable points in the soil.

In 1942 Richards (*12*) described a tensiometer suitable for soil-moisture studies. Later, the work of Kelley and others (*6*) indicated that where periodic readings of soil moisture are desirable at various depths, the Richards tensiometer and the Bouyoucos block are not only convenient tools in maintaining such records under field conditions but, because they measure soil-moisture tension, they may reveal better than other devices how the soil-moisture conditions are actually affecting the plant.

MATERIALS AND METHODS

The carrot experiments were conducted with the Red Core Chantenay variety. Medium-size stecklings (1–1½ inches diameter) were grown at the Utah Agricultural Experiment Station from commercial-stock seed. For the onion experiments, mother bulbs of the foundation stock of the Utah strain of Yellow Sweet Spanish variety were supplied by the Utah Agricultural Experiment Station, except in 1950. In that year it was desirable to conduct the experiment with a seed-to-seed crop, and so the Station's foundation-stock seed was planted. The mother bulbs were about 3 inches in diameter. The use of such material assured an above-average uniformity of plant materials in both the carrot and onion crops.

With carrots, the yield data were collected from a single-row plot 50 feet long in 1946 but only 42 feet long in succeeding years and always 3 feet wide. With onions, the plot length was 50 feet in 1946, 35 feet in 1947, 1948, and 1949, and 32 feet in 1950. Guard rows separated the record rows in the adjacent plots of carrots by 12 feet, and of onions by 11 to 12 feet.

For one year, 1946, separate experiments were conducted in spacing and frequency of irrigation. Spacings with carrot stecklings at 6, 12, 24, and 36 inches in the row were compared in a randomized-block experiment with four replications. No spacing study was conducted with onions that year. In a frequency-of-irrigation experiment with

both onions and carrots, irrigations at intervals of 5, 10, and 15 days were used.

Beginning in 1947, soil moisture and spacing were always studied in combination. Haddock and Kelley had already begun their recently reported Utah experiments (*3*) to study the interrelationship of moisture, spacing, and soil fertility in the production of sugar beets. On the basis of their unpublished findings in 1946, it seemed desirable to maintain a high level of fertility in the carrot- and onion-seed experiments if the study were to be limited to spacing and soil moisture only. In both experiments, therefore, 150 pounds of P_2O_5 (approximately 300 pounds of triple superphosphate) per acre and 30 to 35 pounds of nitrogen (either in the form of ammonium sulfate or ammonium nitrate) per acre were applied each year, except in 1950 when 60 pounds of additional nitrogen was added in the irrigation water.

In 1947 and 1948, the experiments were conducted on a Millville gravelly loam soil at Logan, Utah. In 1949, the work was transferred to a Millville loam soil at the same location. In 1950, the onion experiment was conducted on a Draper gravelly loam[3] at Farmington, Utah.

In line with the studies by Kelley and coworkers (*7*), soil-moisture levels rather than frequency of irrigation were used as the basis for comparison. Irrigation simply became a means of maintaining the soil-moisture level within certain limits. Three soil-moisture levels were arbitrarily set up for four experiments: two each for carrots and for onions. These levels were as follows:

(1) For high levels the soil-moisture tension was kept constantly below 500 cm. at the 6-inch depth in the plots with the closest spacings in 1947. In 1948 and 1949 the depth of measurement was changed to 18 inches for the carrots and 12 inches for onions. The 12-inch depth was used for onions in 1950 also.

(2) For medium levels all plots were irrigated in 1947 when the soil-moisture tension at the 6-inch depth was equivalent to the wilting percentage; in 1948, 1949, and 1950 the depth of measurement was raised to 3 inches in the onion plots but left at 6 inches in the carrot plots.

(3) For low levels the carrot plots were irrigated in 1947, 1948, and 1949 when the soil-moisture tension at the 24-inch depth was equivalent to the wilting percentage; the treatment was the same for onions in 1947, but in 1948, 1949, and 1950 the depth was reduced to 6 inches. Also, in 1950 the various soil-moisture levels were maintained in each spacing separately.

Superimposed upon each moisture plot in the carrots were four spacing treatments within the row. In 1947 these spacings were 6, 12, 24, and 36 inches; in 1948 and 1949 they were 3, 6, 12, and 24 inches. The treatments were arranged by dividing the long (168 feet) soil-moisture plot into four plots each 42 feet long.

In the onion experiment, each moisture plot had the following spacings between the rows: In 1947, 20 and 36 inches; in 1948 and 1949, 20 and 30 inches; in 1950, 9, 18, and 36 inches. From 1947 to 1949, data were recorded for only one row. In 1950, one, two, and four rows were harvested from 36-, 18-, and 9-inch spacings, respectively, embracing

[3] Tentative classification by the Division of Soil Survey, of this Bureau.

an area of uniform size from each treatment. Actually, in the so-called 9-inch spacing, the rows were paired, the rows of each pair were approximately 6 inches apart and the space between pairs was 12 inches. The spacing treatments were superimposed on the moisture plots by splitting the plots lengthwise. All moisture treatments were randomized within replications; and, except in 1947, when the spacing plots in the onions were arranged in strips across all soil-moisture plots, all the spacing treatments were randomized within moisture plots.

Tensiometers and gypsum (plaster-of-paris) blocks were used to determine the soil-moisture tension. The tensiometers were used in all high-moisture plots except in 1950, when blocks were used. The blocks were also used in all medium- and low-soil-moisture treatments. The measuring devices were always placed in the row toward the lower end of the plot. They were placed at the depths specified earlier to determine when to irrigate and were also arranged so that soil-moisture tension could be recorded from a depth of only 3 inches in onion plots to 5 feet in the carrot plots.

A bridge was used to determine the electrical resistance, in ohms, of the gypsum blocks. Under the conditions of these experiments, readings of 600 to 1,000 ohms, depending upon the composition of the blocks, were obtained when the soil was at approximately field capacity (following an irrigation). When readings of about 100,000 ohms were obtained it was assumed that the wilting percentage had been reached.

In 1947, readings were obtained at the two extremes of spacing in both carrots and onions, as well as at some of the intermediate spacings in the carrot plots in all replications. Moisture values in replicate plots were so remarkably similar that records were believed necessary for only three replications in the following years.

Considerable effort was made to control weeds in all soil-moisture experiments, as it was believed that a heavy weed growth could easily lead to incorrect conclusions. Generally, the plots were kept freer of weeds than is considered practicable under commercial conditions. In the carrots, weeds in the row were sprayed while they were still small with Stoddard solvent, the same type of spray commonly used in carrot fields grown from seed. In the onions, weeds had to be controlled by both cultivation and hoeing early in the season and by hoeing alone after seedstalks made their appearance. It was impossible to keep the onions entirely free of weeds.

Since the treatments often greatly influence the height and growth habit of the plants, notes were taken in most years on these characteristics. Typical height and the extremes of height in healthy plants were recorded for each plot. Similarly, the branching habit in the carrot was recorded by range and mode of number of branches observed on the plants of a given plot or treatment. Only the modal measurements are presented in this report.

When the second-order heads of carrot were turning brown, the plants were pulled and windrowed. In line with commercial practice, all onion seed heads were cut or twisted off when a scattering of black seed was visible in heads throughout the plot, and before any shattering had occurred. The yields reported in this publication have all

been based on the weight of seed harvested, cleaned, and recleaned in accord with good commercial practice. A sample for germination test [4] was taken from each experimental lot of seed throughout the course of these studies by the use of a Boerner sampler, thus assuring that each sample would be representative of the original lot.

All of the experiments were designed so that a statistical analysis could be made of the data. The conclusions presented are based on these analyses.

HAILSTORM OF 1948

In 1948, all experimental plantings were seriously injured by a hailstorm on July 24. The storm defoliated the majority of the carrot plants and broke or injured many of the seed heads. The developing seed was still immature and there was little shattering. Probably the most serious damage done by the hail was the defoliating of the plants. Carrot plants continued to mature despite the injuries sustained. Although it is estimated that yields were cut 35 to 45 percent, an analysis of the data still shows differences of statistical significance with different spacings; hence yields and other data for 1948 have been presented with those of other years.

The storm damaged the onions much more seriously than the carrots, reducing seed yields by an estimated 90 percent. Seedstalks and leaves were snapped off; a completely uninjured seedstalk and head was rare. Since this work was done with valuable foundation stock, the experiment was carried through to completion. Despite the storm damage, the effects of the soil-moisture treatments on the seed yields were measurable, but those attributable to spacing were not.

SOIL-MOISTURE TENSION AS INFLUENCED BY IRRIGATION, SPACING, AND RAINFALL

As already indicated, the frequency of irrigation was determined by the readings of soil-moisture tension at various arbitrary depths below the soil surface. The data in table 1 show that the number of irrigations was fairly uniform in all years in both carrot and onion plots, except in the high soil-moisture treatment. Because of the change in treatment after the first year, the number of irrigations for high soil moisture was decreased in 1948 and 1949. Although the high soil-moisture treatment in the onion experiment was continued through 1950 at the same level as in 1948 and 1949, as many irrigations were required in 1950 to maintain that level as had been necessary in 1947, when the moisture level had been set much higher. Gravelly subsoil undoubtedly tended to create a droughty condition in 1950.

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[4] All the germination tests were made by official methods under the direction of E. H. Toole, at the Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Md.

TABLE 1.—*Number of irrigations and estimated acre-inches of water applied in each soil-moisture experiment with carrots and with onions, 1947–50*

CARROTS

Soil-moisture level	Irrigations				Quantity of water applied [1]			
	1947	1948	1949	1950	1947	1948	1949	1950
	Number	*Number*	*Number*	*Number*	*Acre-inches*	*Acre-inches*	*Acre-inches*	*Acre-inches*
High [2]	[3] 13	7	4	-------	19	11	6	------
Medium	2	2	2	-------	9	9	5	------
Low	1	1	0	-------	6	6	0	------

ONIONS

Soil-moisture level	1947	1948	1949	1950	1947	1948	1949	1950
High [2] [4]	11	6	6	[5] 11	16	10	10	14
Medium [4]	1	1	2	[6] 3	3	4	8	12
Low [4]	0	1	0	1	0	5	0	5

[1] Estimated.
[2] Lowering of the high soil-moisture level in 1948 and 1949 (see p. 4) decreased the number of irrigations needed.
[3] Nitrogen in the form of ammonium nitrate, at the rate of 33 pounds per acre, was added to the water in an attempt to overcome the chlorotic condition caused by frequent irrigation.
[4] All levels for onions were slightly different in 1947 from those in other years. (See p. 4).
[5] There were 12 irrigations in the plot with 9-inch spacing.
[6] There were no irrigations in the plot with 36-inch spacing.

Although the quantity of water applied was never measured in these studies, a fairly accurate estimate of the acre-inches used in 1947 and 1948 (table 1) was obtained by calibrating the soil-moisture-retention curves of the soils used against the moisture-tension readings. The estimates given for 1949 and 1950 are somewhat less accurate, as soil-moisture-retention curves were not available and other methods of estimating had to be followed. More water actually was applied than is indicated by the acre-inches of water given in table 1, because there had to be a slight runoff. This was always held to a minimum, however.

Frequent irrigation does not necessarily mean that a correspondingly greater amount of water is taken up by the soil. For example, had the 13 irrigations given to the high-moisture plots of carrots in 1947 (table 1) added as much water per irrigation as one irrigation did in the low-moisture treatment, then the high-moisture plots would have received a total of about 78 inches of water for the season. Although there were obvious differences in the amounts of water applied, there were greater differences in the number of irrigations necessary to maintain certain levels of soil moisture.

The extent to which the soil became dry (soil-moisture tension increased) at various depths with plants grown at different spacings may be observed in the graphs of figures 1 and 2, which are typical

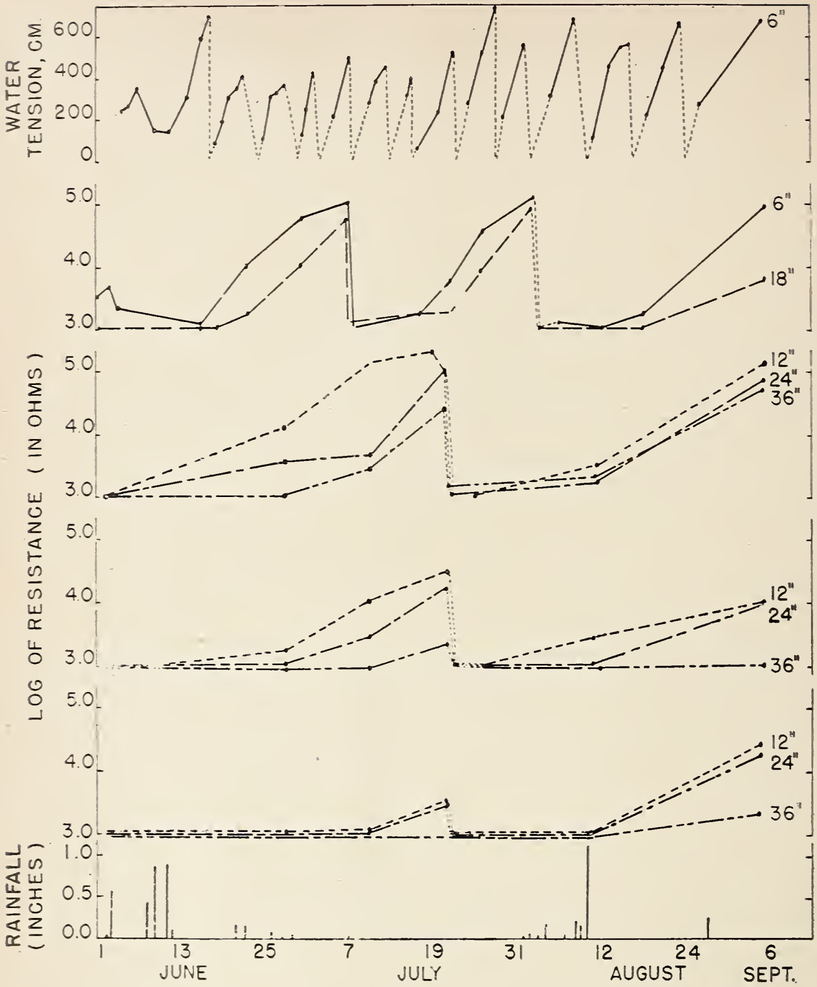

FIGURE 1.—Rainfall and soil-moisture tension in representative plots of the carrot-seed crop in 1947: *A*, High moisture, 6-inch spacing, 6-inch depth; *B*, medium moisture, 6-inch spacing, 6- and 18-inch depths; *C*, low moisture, 6-inch spacing, 12-, 24-, and 36-inch depths; *D*, low moisture, 12-inch spacing, 12-, 24-, and 36-inch depths; *E*, low moisture, 36-inch spacing, 12-, 24-, and 36-inch depths.

of a large number constructed in connection with this study. More satisfactory results were obtained with onions than with carrots, because the shallower root system of the onions introduced no complications involving removal of water from soil depths lower than 3 feet.

The soil-moisture-tension readings at the lower depths in the carrot plots were never so completely satisfactory as they were in the onion plots. In 1947 it was obvious that the gypsum blocks had not been placed deep enough in the lower soil-moisture treatments to determine how far down the carrot roots were absorbing water, for the soil at the maximum recording depth (36 inches) in the low-soil-moisture

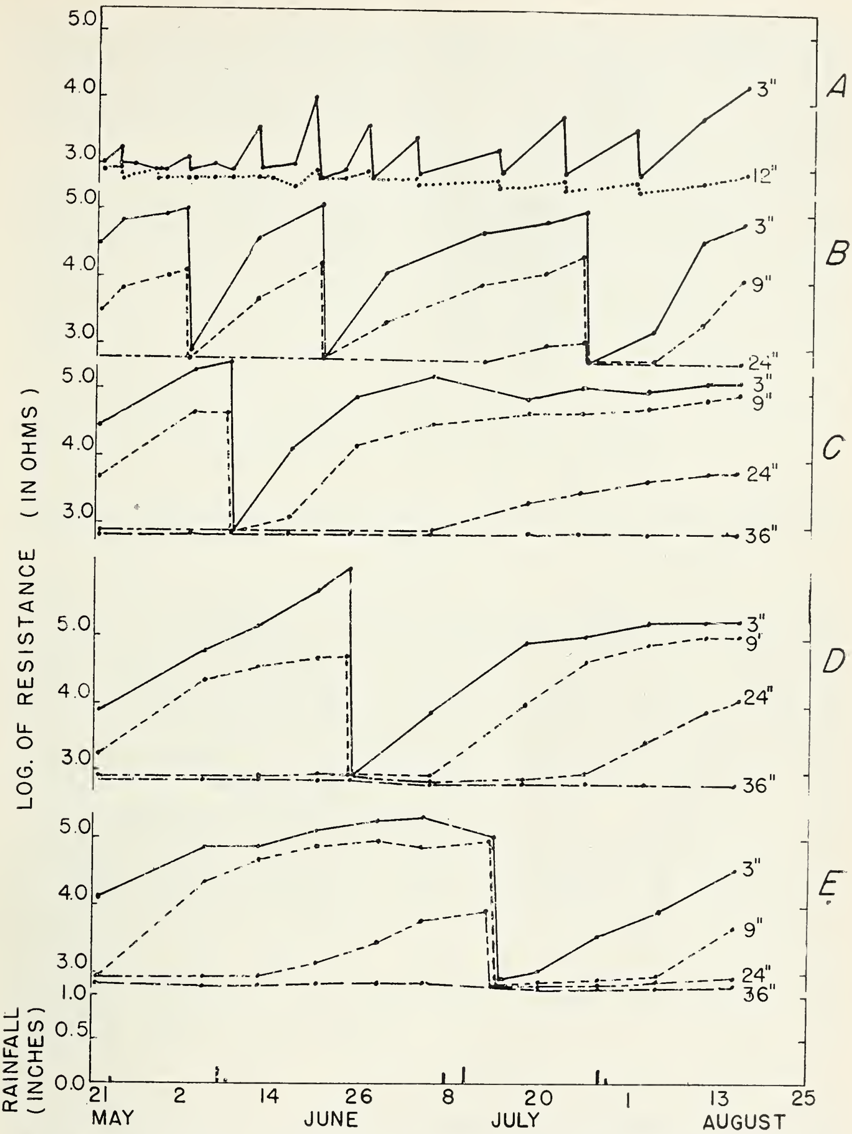

FIGURE 2.—Rainfall and soil-moisture tension in representative plots of the onion-seed crop in 1950: *A*, High moisture, 9-inch spacing, 3- and 12-inch depths; *B*, medium moisture, 9-inch spacing, 3-, 9-, and 24-inch depths; *C*, low moisture, 9-inch spacing, 3-, 9-, 24-, and 36-inch depths; *D*, low moisture, 18-inch spacing, 3-, 9-, 24-, and 36-inch depths; *E*, low moisture, 36-inch spacing, 3-, 9-, 24-, and 36-inch depths.

treatment became fairly dry (fig. 1, *C*). In the latter part of the 1948 season, moisture-tension readings at the lower depths failed to exhibit normal tendencies, because of the effects of the hailstorm, which almost completely defoliated the plants and reduced their capacity to

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remove water from the soil. In 1949, an unexpectedly high water table vitiated the soil-moisture-tension readings below 3 feet and may have indirectly affected the readings at shallower depths early in the season. In the spring, the water table was 3 feet below the soil surface, but by midsummer it had dropped to 5 feet in most locations and to 6 feet in some places in these fields.

A comparison of *C*, *D*, and *E* in figure 1 shows that in the low-soil-moisture treatment during the carrot study in 1947, the closer the plants were spaced the higher was the moisture tension just preceding irrigation. Had the experimental field design permitted, irrigation could have been postponed in the wider spacings. Whenever it was possible to reach the maximum arbitrary moisture tension before applying water in the 1950 spacing treatment of onions, the date of the single irrigation in the low-moisture plots was made progressively later, as the width between rows increased (fig. 2, *C*, *D*, and *E*).

Figures 1, *A*, *B*, *C*, and 2, *A*, *B*, *C*, illustrate the type of soil-moisture-tension curves obtained from periodic readings taken at the same spacing but for different moisture treatments in the carrot and onion experiments, respectively. The graphs indicate that the lower the level of the soil-moisture treatment, the greater is the depth to which the soil became drier, that is, to which the soil-moisture tension increased. In the high soil-moisture treatment (figs. 1, *A*, and 2, *A*), it was impossible to obtain any indication of the greatest depth from which the plants might be absorbing water. The moisture tension of the surface 6 and 3 inches of soil for carrots and onions, respectively, fluctuated within a narrow range, but at a short distance below these depths the soil gave moisture-tension readings equivalent to field capacity. However, as illustrated by figures 1, *C*, and 2, *C*, the soil in the low-moisture treatment at depths as great as 3 feet in the carrot plots and 2 feet in the onion plots was losing water for some time prior to irrigation. This became more noticeable as the season advanced, indicating that the roots were absorbing water to a greater extent at the lower depths than they had earlier. About the middle of July 1950, the soil-moisture tension increased even at a depth of 2 feet in the onion plots with 9-inch spacing and medium-moisture treatment (fig. 2, *B*).

Although the evidence during the years 1947, 1948, and 1949 is unfortunately inconclusive concerning the soil-moisture tension at depths greater than 3 feet under a carrot-seed crop, the carrot undoubtedly draws moisture from such depths. The extent to which the soil-moisture tension increased at the 3-foot depth in 1947 in the closely spaced carrots in the low soil-moisture treatment indicated that the roots below that point must have been absorbing water. In a 1950 experiment the soil-moisture tension at a depth of 4 feet increased just as greatly, which indicated that water absorption was probably going on at even greater depths.

The effect of rainfall on soil-moisture tension was generally much less than might be expected. A single precipitation of about 0.5 inch would only affect the moisture tension at depths as shallow as 3 or occasionally 6 inches. In 1948, there was a total precipitation on the plots of 1.8 inches during 5 successive days, June 19 to 23. The resistance of a block at the 6-inch depth was 12,500 ohms on June 17 and on June 24 it was only 1,250. This shows the effect of the rain.

In contrast, a block in the same location, buried at 12 inches, gave resistance readings of 1,850 and 2,500 ohms for June 17 and 24, respectively. In spite of the rain, the resistance had increased, indicating that the soil had actually become slightly drier at that depth.

In view of the facts just stated, it is believed that any precipitation of less than 0.5 inch was ineffective in adding materially to the soil moisture unless there was additional rainfall on the days immediately following, thus making the over-all amount much greater. The soil-moisture-tension readings taken in various treatments in both carrot and onion plots following small rains repeatedly supported this idea. The total precipitation estimated to be effective for the crops, from the time the plants were set out in late March or early April, was 7.95, 8.61, and 5.20 inches, in 1947, 1948, and 1949, respectively. In 1950, in a similar period from April to August, inclusive, the estimated effective rainfall was 4.10 inches. Rainfall for the 1947 and 1950 seasons has been indicated in figures 1 and 2, so that the effect on the soil-moisture curves may be observed.

EFFECT OF SOIL MOISTURE AND SPACING ON CARROTS

Seed Set

Each year estimates were made of the percentages of flowers that set seed in the first-, second-, and third-order umbels. The central umbel, or head, of a carrot plant with one central main stem is spoken of as first order; the branches coming directly from the main stem bear the second-order heads; and from each of the second-order branches several third-order branches with heads may arise. Fourth-order umbels may be observed on widely spaced plants, but they rarely produce any appreciable amount of seed.

A 100-percent set of seed in an umbel does not necessarily mean that the yield from that head will be high, because the heads vary in size. The percentage of flowers setting seed, however, does have an effect on the potential production from the plant. Theoretically, a plant with comparatively few heads might produce a greater amount of seed than one with many. Thus, the data on the extent of seed set, while perhaps not of primary importance in comparison to the ultimate amount of seed produced per acre, do aid in understanding why such yields are obtained.

SOIL MOISTURE

Soil moisture had no observable effect on the percentage of flowers setting seed. This statement applies equally well to first-, second-, and third-order heads.

SPACING

Spacing had a much more noticeable effect than did soil moisture on the extent of seed setting. The effect of spacing was greater than that recorded in an earlier report for size of root (*4*). Flowers in the central, or first-order, head of healthy plants nearly always set seed 100 percent, regardless of spacing. This was also true for the majority of second-order heads. In 1947, however, second-order heads on plants spaced 6 inches apart set only about 80 percent of

their flowers. In 1948, when the plants as a whole were much smaller than normal, allowing much more light to penetrate between them, the second-order heads, even on plants spaced 3 inches apart, set practically 100 percent.

The greatest differences in seed set were observed in third-order heads. In 1947, the set on such heads ranged from 30 percent on plants spaced 6 inches apart to 95 percent on plants spaced 3 feet apart. In spite of the introduction of the 3-inch spacing in 1948, seed set that year on the third-order heads ranged from 80 percent on plants spaced 3 inches apart to 95 percent on those spaced 2 feet. Of course, the hailstorm had an adverse effect on the final yield because it injured the crop after most of the seed was set.

Plant Height and Branching Habit

SOIL MOISTURE

Soil moisture had only a slight effect on the height and the branching habit of the carrot-seed plant. It is true that in 1947 the plants in all treatments were much taller than in later years (table 2) and that precipitation was above normal during May and June. Although some of the additional height was probably caused by the extra precipitation, some of the conditions associated with rainy weather, such as cloudiness, lower temperatures, and high relative humidity, undoubtedly had an influence on the carrot-plant growth of that year.

Table 2.—*Height and number of main branches of Red Core Chantenay carrot-seed plants as influenced by spacing, 1947 through 1949*

Spacing in the row (inches)	Modal height of plants			Main branches per plant	
	1947	1948	1949	1947	1948
	Inches	*Inches*	*Inches*	*Modal number*	*Modal number*
3		36	39		6
6	52	36	39	7	7
12	50	34	36	9	8
24	42	31	33	10	9
36	41			10	

The soil moisture during late June, July, and August, when the experimental treatments were being applied, had only a slight effect on plant height, and then chiefly in 1947. In that year, the plants spaced 6 inches apart had a modal height of 60 inches in the high soil-moisture treatment, as compared with only 48 inches for plants similarly spaced in the medium and low soil-moisture treatments. The plants spaced 12 inches apart, likewise, were a foot taller (54 as compared with 42 inches) in the wettest soil treatment. Such differences were extremely small in the following years. It should be re-

membered that in the high soil-moisture treatment not nearly so many irrigations were necessary in 1948 and 1949 as in 1947 (table 1). Soil-moisture differences were unrelated to the number of branches produced.

SPACING

Spacing had a noticeable effect on both height of plant and number of main (second-order) branches produced by carrot (table 2). The closer the spacing the taller the plant, but the fewer the branches it was likely to have. Regardless of height, carrot plants tended to have approximately the same number of main branches in any given treatment. As can be seen from table 2, there was a great difference in height in 1948 as compared with that in 1947, and yet the numbers of branches each year were identical in some spacings and nearly the same in others.

The tallest plants (66 inches) were in the 6-inch spacing of the high soil-moisture treatment in 1947. The smallest plants (27 inches) were recorded in several of the wider spacings of both the medium- and low-moisture treatments in 1948.

Carrot plants grown from medium-size stecklings had from about 6 main branches when spaced 3 inches apart in 3-foot rows to about 9 or 10 when spaced 2 or 3 feet apart (table 2). Detailed observations indicate that plants spaced as close as 3 inches apart may have as few as 4 main branches, but when spaced 3 feet the number may be as high as 15.

Time of Seed Maturity

SOIL MOISTURE

The level of soil moisture had a definite effect on the time of seed maturity and, thus, indirectly on the time of harvest. In 1946, when irrigations were given every 5, 10, and 15 days, the most conspicuous result was the difference in time of maturity. That year, plots irrigated every 5 days matured 2 weeks later than those irrigated every 15 days. Results from the 10-day treatment were intermediate.

During the years 1947 and 1949, soil moisture had the same general effect as in 1946. Plants receiving the least irrigation always flowered and matured first, and those in plots receiving the most irrigation flowered and matured last. The effect was always most conspicuous during the flowering period. The difference in time of maturity between the plants in the "dry" and "wet" plots varied from 10 days to 2 or 3 weeks. The "wet" plots also usually required more time to become sufficiently dry for threshing. This was probably because the plants had a higher moisture content, and also the weather in late September or early October was not usually so favorable for curing as that in early September.

SPACING

Although spacing had a more noticeable effect than did soil moisture on a number of characteristics, it had no influence on time of seed maturity, so far as could be observed. Plants spaced close together matured at the same time as plants spaced widely, as long as soil-moisture conditions were the same.

Seed Yield

SOIL MOISTURE

Soil moisture had a measurable effect on the yield of recleaned carrot seed in 2 out of 4 years. In 1946, when frequency of irrigation rather than soil moisture was studied in a preliminary way, there was no significant difference in the yield of the seed obtained. There was a tendency, however, for the carrots in the least frequently irrigated plots to yield the most seed. The numbers of irrigations were 15, 7, and 5 for the 5-, 10-, and 15-day frequencies, respectively. In the light of later experiments reported, the results obtained in 1946 are not surprising. From what is now known, 5 irrigations, or an estimated total of about 10 acre-inches of water, are excessive under ordinary circumstances in northern Utah, especially for carrots spaced 1 foot apart in 3-foot rows.

The seed yields resulting from the various soil-moisture treatments from 1947 to 1949, inclusive, are presented in table 3. The lack of consistent results during this 3-year period may be attributed in part to the change in treatment after 1947. Also, in 1948 the hailstorm seriously upset the experiment and yields did not reflect any effect of soil moisture that year. It is estimated that the yields were cut between 35 and 45 percent.

Table 3.—*Effect of various amounts of soil moisture on the yield of Red Core Chantenay carrot seed, 1947 through 1949*

Soil-moisture level	Irrigations			Yield per acre [1]		
	1947	1948	1949	1947	1948	1949 [2]
	Number	*Number*	*Number*	*Pounds*	*Pounds*	*Pounds*
High	13	7	4	572	611	1, 492
Medium	2	2	2	808	615	1, 532
Low	1	1	0	834	647	1, 364
Least significant difference at odds, 19:1	--------	--------	--------	99	--------	134

[1] Average of all plots in a given soil-moisture treatment regardless of spacing.
[2] Yields adjusted for stand in 1949.

In 1947, high soil moisture (13 irrigations) resulted in 572 pounds of seed per acre, a yield decidedly lower than that obtained in either the medium or low soil-moisture treatment. As already indicated, the yield data in 1948 meant little so far as soil moisture was concerned. The nonsignificant differences, however, were in favor of less irrigation. In 1949, with the carrots on a different soil type, with a high water table, and with the high- and low-moisture treatments reduced to 4 and 0 irrigations, respectively, the lowest yield of seed was obtained from the low soil-moisture treatment. This result reversed the trend of the previous years. Even then, the low-moisture treatment averaged 1,364 pounds per acre. Only the yield (1,532 pounds) from

the medium-moisture treatment with 2 irrigations significantly exceeded this. Where 4 irrigations were given, as in the high soil-moisture treatment, the yield was 1,492 pounds. While not significantly lower than the yield from 2 irrigations, this value again suggested that high moisture content does not give the best yields.

The yield in grams of recleaned seed per plant closely paralleled that on an acre basis. In 1947, a plant in the "wet" soil treatment produced an average of 29.6 gm. as compared with 42.0 gm. from a plant in the "dry" soil treatment. In 1948, the year of the hail, the average yield in all soil-moisture treatments was about 15 to 16 gm. per plant. The seed yields per plant in 1949 were similar to those of 1947 except that the yield in the "dry" soil treatment was the lowest for any year.

SPACING

The differences between carrot-seed yields resulting from variations in spacing within the row have always been more distinct and consistent than those from variations in soil moisture (table 4). The closer the spacing, the higher has been the acre-yield of recleaned seed.

Table 4.—*Effect of spacing on the yield of Red Core Chantenay carrot seed, 1946 through 1949*

Spacing in the row [1]					Yield of recleaned seed per acre [2]			
Initial	Final average				1946	1947	1948	1949 [3]
	1946	1947	1948	1949				
Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
3	------	------	3. 3	3. 5	-------	-------	778	1, 815
6	6. 3	6. 9	6. 4	7. 5	1, 169	884	730	1, 641
12	12. 3	15. 4	12. 3	13. 1	987	818	627	1, 446
24	24. 2	27. 0	24. 5	27. 0	828	706	363	950
36	36. 4	42. 0	------	------	508	544	-------	-------
Least significant difference:								
Odds, 19 to 1					66	131	67	89
Odds, 99 to 1					94	176	90	119

[1] Stecklings were planted at the exact distances given under the heading "Initial." Losses in stands each year changed the spacing. The resulting figures for each year are given under the heading "Final average."

[2] Average of all plots in a given spacing, regardless of the soil-moisture treatment.

[3] Yields adjusted for stand in 1949.

In 1946, when all spacings were irrigated alike, the yield ranged from 508 pounds per acre where the plants were 36 inches apart up to 1,169 pounds at 6 inches. In 1947 the trend was similar but the range was not so wide, starting at 544 pounds for the 36-inch spacing and ending at 884 pounds at 6 inches. Even in 1948, the year of the hailstorm, there was a range from 363 pounds in the 24-inch spacing (the

widest that year) to 730 pounds at 6 inches and 778 pounds at the 3-inch spacing (the closest). Yields at all spacings were much higher in 1949 than in earlier years, ranging from 950 pounds at 24 inches to 1,641 pounds at 6 inches and 1,815 pounds at 3 inches.

The yields in grams per plant showed a reverse trend to that exhibited by the yields per acre. The wider the spacing, the greater was the yield per plant. In 1947, apparently an average year, the yield per plant varied from 16.2 gm. of seed from plants spaced 6 inches apart to 58.2 gm. from plants spaced 36 inches apart.

COMBINED EFFECT OF SOIL MOISTURE AND SPACING

The yields obtained as a result of the combined effect of soil moisture and spacing are presented in table 5. These yields obviously show a greater range than where they have been averaged only for moisture (table 3) or for spacing (table 4). An analysis, however, of each of the 3 years' results from the three moisture levels and the several spacings shows no significant effect of moisture upon the way plants responded to spacing, nor a converse effect.

TABLE 5.—*Yield of Red Core Chanteney carrot seed per acre, as influenced by the combined effect of soil moisture and spacing, 1947 through 1949*

Soil-moisture level	Plant spacing in row	Yield of recleaned seed per acre		
		1947	1948	1949 [1]
	Inches	*Pounds*	*Pounds*	*Pounds*
High	3	----------	796	1, 977
	6	710	693	1, 656
	12	645	585	1, 455
	24	509	370	882
	36	425	----------	----------
Medium	3	----------	761	1, 829
	6	877	706	1, 701
	12	913	643	1, 545
	24	806	351	1, 051
	36	634	----------	----------
Low	3	----------	777	1, 638
	6	1, 065	791	1, 566
	12	895	652	1, 338
	24	802	368	916
	36	574	----------	----------
Least significant difference between spacing, within moisture levels:				
Odds, 19 to 1		76	39	51
Odds, 99 to 1		102	52	69

[1] Yields adjusted for stand in 1949.

VIABILITY OF SEED

The percentage germination of the harvested seed was, in general, little affected by either soil moisture or spacing (table 6). In 1948

the germination in all soil-moisture treatments was below 80 percent, and this is believed to be the result of the hailstorm in that year. Although there seemed to be a difference in viability in some years between the seed harvested from the various treatments, analyses of the data failed to show any significant differences, except in the effect of soil moisture in 1949. In that year, the average percentage germination of the carrot seed from the high soil-moisture treatments, regardless of spacing, was 77.74 percent in comparison with 82.72 percent for the medium-moisture treatment and 83.19 percent for the low-moisture treatment. Although there was no significant difference in germination between the medium- and low-moisture treatments, the germination record from the high-moisture treatment was distinctly below either of them.

TABLE 6.—*Percentage germination of recleaned Red Core Chanteney carrot seed as affected by soil-moisture conditions under which the seed crop was grown, 1946 through 1949*

Soil-moisture level	Germination			
	1946	1947	1948	1949 [1]
	Percent	*Percent*	*Percent*	*Percent*
High	81. 62	91. 25	71. 44	77. 74
Medium	83. 75	89. 62	75. 38	82. 72
Low	81. 50	89. 54	74. 92	83. 19

[1] Least significant difference (odds, 19 to 1), 3.32. Other years not significant.

In view of the nonsignificance of differences observed in 1946, 1947, and 1948, together with the comparatively small differences in 1949 and the fairly general high percentage of germination obtained in all years, it may be concluded that soil moisture does not have any marked effect on viability of recleaned seed in most years. Under practical conditions, if soil moisture is maintained at a low or moderate level rather than a high one, there should be no ill effects on germination.

The data on the germination percentages associated with spacing are not presented, because all the differences were slight and were not attributed to spacing.

SIZE OF SEED

Seedsmen prefer moderately large, well-formed seed. Seed growers who have inspected these experiments have repeatedly asked if either water or spacing, and especially the latter, had any effect on the size of seed harvested. No consistent differences caused by either of these factors could be discovered. Such differences possibly may exist, but if they do they are so minute that ordinary methods of measuring do not reveal them and therefore they are of no practical consequence.

EFFECT OF SOIL MOISTURE AND SPACING ON ONIONS

Blasting of Flowers and Seeds

At the beginning of these studies it was expected that some variable degrees of blasting of flowers or seeds would be encountered in some of the low-moisture plots, at least in some years. Blasting sometimes causes serious losses to seed growers. It involves the browning, death, and shriveling of flower or seed to an extent ranging from a small percentage to complete loss of the flower or seed head.

Careful observation throughout the tests failed to reveal any appreciable or consistent amount of blasting that could be ascribed to any of the spacing or irrigation treatments.

Plant Height and Seedstalk Formation

Unlike the carrot, the onion showed virtually no effect of either moisture or spacing on the height of plant or the number of seedstalks in 1947, 1948, or 1949. In 1950, with the crop grown seed-to-seed, the extremely close spacing of the onion plants in some treatments, both in the row and between the rows, caused a slight difference in plant height. Plants in the high-moisture plots had a modal height of 41 inches; those in medium-moisture plots, 36 inches; and those in the low-moisture plots, 35 inches. However, an analysis of the data indicated that the differences were not significant. It was found that differences in plant height under different spacing treatments were even less than those resulting from various degrees of soil moisture.

Time of Seed Maturity

Soil moisture had no noticeable effect on time of seed maturity in the onion crop. In the preliminary study in 1946, there was no recordable difference. In the following years, including 1950 with its rather extreme treatment differences, the onions in the medium and low soil-moisture treatments tended to mature a day or two ahead of those in the high soil-moisture plots, but the effect was not clear cut. The difference was perhaps most noticeable in 1950. Even then, however, harvesting in the high soil-moisture plots could not be postponed more than 1 day after seed of the other treatments had been harvested, lest seed be lost by shattering.

No difference in time of maturity could be attributed to spacing.

Seed Yield

There was a distinct trend in 1947, 1949, and 1950 toward increased seed yields as the spacing was narrowed. Yields were also increased at the close spacings by maintaining high levels of soil moisture (fig. 3). Even in 1948, when the hailstorm reduced the yields to only 10 percent of normal, there was a distinctly higher yield at the highest soil moisture. As the highest yields that year were considerably below 100 pounds per acre, the data were not analyzed along with those of the other years.

The lines in figure 3 indicate that for every inch the onion rows were moved closer together between 36 and 9 inches, the yield of recleaned

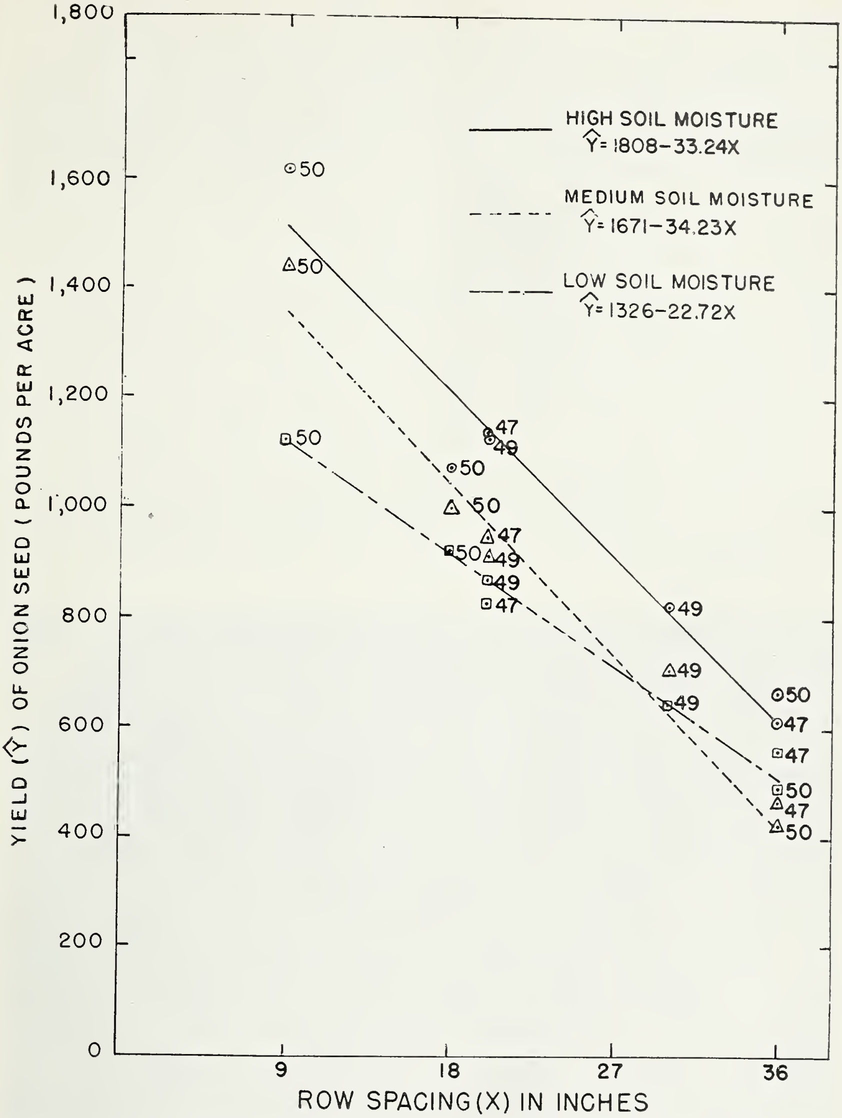

FIGURE 3.—The relationship of onion-seed yield (adjusted for differences in years) and spacing at three levels of soil moisture in northern Utah, 1947, 1949, and 1950.

seed increased by 33.2 ± 5.6 pounds per acre where the soil moisture was maintained at a high level. The corresponding figure under medium-moisture conditions was 34.2 ± 4.5, and that for plants grown under low-moisture conditions, 22.7 ± 3.3. The analysis of the data shows that the difference between the slope of the low-moisture curve and that of either the medium- or high-moisture curve is highly significant. This means that at spacings closer than about 30 inches it is im-

portant to maintain the moisture at a high or at least a medium level to obtain a yield of seed that is relatively good for wide spacing.

In commercial bulb-to-seed plantings of Yellow Sweet Spanish onions, normally in rows 33 to 36 inches apart, average seed yields range from about 300 to 600 pounds per acre. The yields obtained in these studies at a spacing of 36 inches correspond well with such commercial records. The studies also show, however, that if onion rows are spaced closer together, up to as close as 9 inches apart, yields of more than 1,500 pounds per acre may be realized where the soil moisture is maintained at a high level, and over 1,100 pounds at a low-moisture level. An average yield of 1,797 pounds was obtained at the 9-inch spacing in the high-moisture plots in these studies in 1950 (fig. 4), but this was partly the result of the seed-to-seed method, which gives many more plants per foot of row and therefore normally results in higher seed yields. At both the medium and high soil-moisture levels, seed yields from seed-to-seed plantings always tended to be somewhat higher than those indicated by the lines in figure 3.

Although no spacings closer than 9 inches were used, there is evidence that the yields would continue to increase as the spacings are diminished beyond that width. Under practical conditions, placing rows closer than 9 inches apart could introduce difficulties in crop management.

FIGURE 4.—A seed-to-seed planting of Yellow Sweet Spanish onions at harvest-time, with rows spaced 9 inches apart, Farmington, Utah, 1950. This treatment was irrigated 12 times between May 20 and August 16—approximately once a week. The average yield of the 5 replications in this treatment was at the rate of 1,797 pounds per acre. There were few weeds in spite of the frequent watering.

Viability of Seed

The percentage germination of the onion seed has been uniformly high in all soil-moisture and spacing treatments in all years. Usually, it has been over 90 percent. In 1949, seed of the entire experiment averaged 99.2 percent. There were no differences attributable to spacing or to moisture in any year.

Weed Growth

Weeds are often a serious problem in crops of seed onions. They are difficult to control in a crop of bulb onions, but in seed onions, once the seedstalks are fully grown, it is almost impossible to weed the crop mechanically or even with hand tools without breaking many stalks and leaves. Considerable effort was made to control weeds in these experiments, because a heavy and persistent weed growth could have affected soil moisture easily.

From the first year, it was obvious that there was less weed growth in the plots with low soil moisture. A comparison of weed growth in high and low soil-moisture plots is shown in figure 5.

When the 1950 experiment was planned, there was considerable concern about the problem of weeding the plots with rows 9 inches or 18 inches apart. However, except for an extremely light weeding early in the spring before the onions had much growth, the 9-inch spacing did not have to be weeded at all. This was true even in the high-moisture treatment, which that year required 12 irrigations in the 9-inch spacing. The stand of onions was too dense and the resultant shade too great for more than a few weeds to exist. Both the dense stand of onions and the lack of weeds are well illustrated in figure 4. Even in the 18-inch spacing, the weeding problem was not serious. The many additional plants per row in a seed-to-seed planting provide an early shading of a between-row space as narrow as 18 inches.

DISCUSSION AND PRACTICAL CONSIDERATIONS

The results of these studies suggest several practical and profitable cultural practices in the production of carrot and onion seed. With carrots, low soil moisture is often to be preferred to high soil moisture; with onions, high soil moisture, or at least moderate moisture, is nearly always preferable. Closer spacing than generally practiced is practicable and profitable for both crops.

The high yields of carrot seed resulting from close planting of stecklings are in general agreement with those reported from seed-to-seed studies (*5*). In those studies, although the stands were thicker than in the plots with 3-inch spacing reported in this publication, yields were reduced when plants were thinned. For close spacing the production of the additional stecklings required and the problem of their storage are practical considerations. Although some reduction in yield may be expected when small stecklings are planted (*4*), their use would save storage space. Close spacing is an efficient practice, because a given amount of seed may be produced, thereby, on less land than if the plants are spaced more widely.

FIGURE 5.—Weed growth as affected by soil moisture in the plots of Yellow Sweet Spanish onions with rows 3 feet apart. Farmington, Utah, 1950: *A*, Only 1 irrigation between May 20 and August 16: *B*, 11 irrigations during the same period. Note lack of weeds in *A* and heavy weed growth in *B*.

Regardless of the technical relationships among available water, soil-moisture tension, permanent wilting percentage, and the quantity of water added either by rainfall or irrigation, the fact remains that the use of the moisture-resistance bridge and gypsum blocks offers to the commercial seedsmen interested in more efficient seed-production

practices a practical method of knowing when to irrigate. One moisture bridge would normally be sufficient for a company's operations in any one locality. Each contract grower would need three or four gypsum blocks for each field of seed to be irrigated. A field man for the seed company could easily check on the soil moisture in any one field within 15 to 20 minutes, depending upon its size.

If the results of the experiments discussed in this circular are taken as a guide, then to maintain a low soil-moisture condition in the carrot plots, the blocks should be buried 2 feet deep in the row between two plants normally spaced. The crop should be irrigated soon after the average resistance of all the blocks is about 40,000 ohms. Bouyoucos and Mick, in a report on improvements in the electrical resistance method (*2*), state that a resistance of 75,000 ohms characterizes the permanent wilting percentage of a fairly large number of widely different soils. On the basis of these present studies, however, the resistance increases so rapidly after passing 40,000 ohms that for all practical purposes a grower could prepare to irrigate within a day or two after resistance reaches that point.

With an onion planting maintained at a high soil-moisture level, the blocks should be 6 inches deep and the water should be applied as often as the resistance of a majority of the blocks begins to rise, or at least by the time the resistance reaches about 1,200 ohms. With onions spaced as much as 3 feet between rows, moderate or even low soil moisture might be as profitable as high moisture and would certainly require much less labor. Furthermore, in some sections of the West, irrigation water is not always available in the quantity or as often as required to maintain high soil moisture in a field with rows only 20 inches apart. Under such circumstances a spacing of at least 30 inches would be advisable. Blocks would then need to be placed 3 inches deep to provide readings for medium soil moisture or 6 inches deep for low moisture. Irrigation should be applied in either case when the resistance readings reach 40,000 ohms or higher.

It was pointed out in the discussion of the effect of irrigation on soil-moisture tension that to maintain the different soil-moisture levels set up in these experiments there were much greater differences in the numbers of irrigations required than in the quantity of water applied. Every irrigation requires labor. If labor is relatively cheap and the price of seed warrants it, close planting and fairly frequent irrigation of onions seem practicable. If labor is expensive or the supply of water limited, less frequent irrigations could be applied; and, even if the onions are spaced closer than in normal commercial practice, yields could still be satisfactory, although less than where more frequent irrigations are practiced. Minimum irrigation would reduce weed growth and thus further conserve labor. With carrots, where there has been a tendency toward higher seed yields with little, or at the most, moderate irrigation, the practice of frequently irrigating followed by some commercial growers seems especially wasteful of labor and unprofitable.

The conclusion that the soil-moisture requirement of a carrot-seed crop is low rather than high may seem at variance with that of MacGillivray and Clemente (*10*). A study of their data, however, reveals that, although their nonirrigated treatment resulted in the lowest seed yield in 2 out of 3 years, it actually was not significantly lower in 1

(1947) of the 2 years, when the yields obtained were comparable with those recorded in the Utah studies reported in this publication. Also, in those same 2 years, the yield from carrots in the high soil-moisture treatment of the California experiments failed to exceed that from the medium soil-moisture treatment by a significant margin. This would suggest that actually there may be more agreement between the results of the California and Utah studies than appears at first glance. It would be natural to expect some differences in view of the different climatic and soil conditions existing at the two test localities.

The results of the study with onions make the yield data reported by MacGillivray in 1948 (*9*) more understandable. In spite of a trend toward higher seed yields when the soil moisture was maintained at a high level in onions with rows spaced 3 feet apart, the differences between the various treatments were not always statistically significant. In the light of the Utah study here reported, it is now apparent that although seed onions respond to high soil moisture by producing high yields, this result is usually more noticeable when the onions are spaced close together. The differences in seed yield between widely spaced onions grown at different moisture levels are likely to lack significance.

SUMMARY

Stecklings grown from commercial-stock seed of the Red Core Chantenay carrot and mother bulbs of the foundation stock of Yellow Sweet Spanish onion were planted in a series of experiments from 1946 to 1949 at Logan, Utah, to determine the effect of soil moisture and spacing on the growth, time of maturity, seed yield, and viability of carrot and onion crops grown for seed. Beginning in 1947, all the experiments were factorially designed, thus greatly increasing the efficiency of the studies, as well as allowing for a determination of the effect of the two factors in combination. In order to obtain extremely close plantings with onions, the seed-to-seed method of culture was used in an experiment at Farmington, Utah, in 1950. In all experiments after 1947, soil-moisture treatments were not only based on certain arbitrary soil-moisture tensions, but records of soil-moisture tension were maintained from a depth as shallow as 3 inches with onions to as deep as 5 feet with carrots by means of tensiometers and Bouyoucos blocks.

Soil-moisture tension increased progressively to depths as great as 4 feet with carrots and 2 feet with onions when these plants were grown for seed.

A hailstorm in 1948 was severe enough to defoliate the carrots almost entirely at the time they had about finished setting seed, reducing the seed yields an estimated 35 to 45 percent. There was an estimated 90-percent reduction of seed yield in adjacent onion plots.

Soil moisture had no measurable effect on the percentage of carrot seed set on individual heads, but close spacing definitely reduced the percentage set on third-order heads, and in 1 year even on second-order heads.

The effect of soil moisture on height and branching habit of carrot plants was negligible, but the effect of spacing was definitely noticeable. The closer the spacing the taller was the plant, but the fewer the branches it was likely to have.

Low soil moisture hastened carrot-seed maturity as much as 2 weeks or more as compared with date of maturity in the high soil-moisture treatment.

Spacing had no effect on the time of maturity of carrot seed.

Generally, low soil moisture favored a high seed yield in carrots. In 4 years of testing, there was never a clear-cut advantage in favor of high irrigation, and in only 1 year (1949) did the medium soil-moisture treatment result in a higher yield of seed than that obtained from the low soil-moisture plots.

Close spacing, up to 3 inches within the row, definitely favored higher seed yields with carrots. Yields attributable to spacing in the 3 years without hail varied from a low of 508 pounds per acre in the 36-inch spacing in 1946 to a high of 1,815 pounds in the 3-inch spacing in 1949.

The percentage germination of carrot seed was little affected by either soil moisture or spacing. Only in 1949 did an analysis of the data reveal any real difference. This was due to high soil moisture, which evidently reduced the percentage germination of the seed to 77.7 percent in comparison with about 83 percent for seed from the other soil-moisture treatments that year.

Neither soil moisture nor spacing had any measurable effect on the size of carrot seed.

Neither soil moisture nor spacing had any measurable effect on blasting in onions. In most years, even in the low soil-moisture treatment, all evidence of blasting was absent.

Neither soil moisture nor spacing had any measurable effect on the height of onion plants or the number of seedstalks per plant in bulb-to-seed crops. In a seed-to-seed crop, rows as close as 9 inches and low soil moisture tended to cause plants to be several inches shorter than where the spacing was wider and the soil moisture somewhat higher; but the differences between treatments were not significant.

Neither soil moisture nor spacing had any noticeable effect on the time of onion-seed maturity. At the most, the onions in the low- and medium-moisture treatments were about 1 day earlier than those in the high-moisture treatment.

For every inch the onion rows were moved closer together between 36 and 9 inches, the yield of recleaned seed was increased 33.2 ± 5.6, 34.2 ± 4.5, and 22.7 ± 3.3 pounds per acre under conditions of high, medium, and low soil moisture, respectively. A yield of nearly 1,800 pounds of seed per acre was obtained from seed-to-seed onions grown in rows averaging 9 inches apart in the high soil-moisture treatment in 1950.

In general, high soil moisture favored high yields of onion seed, especially in plantings with the rows spaced less than 30 inches apart. At wider spacings the advantage was not always clear-cut, but at a 30-inch spacing, onions yielded highly viable seed at a rate of about 600 pounds per acre, even under low soil-moisture conditions.

Neither soil moisture nor spacing had any effect on the percentage germination of the onion seed harvested.

Weed growth was much reduced by close spacing in onions and was practically eliminated even in the high soil-moisture plots when the onion rows were spaced an average of 9 inches apart. In the low

soil-moisture plots of any spacing, weed growth was always considerably less than where higher moisture conditions prevailed.

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